The complexity and diversity of pyroclastic fallout forming eruptions and deposits: how do we study and classify them?

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Pyroclastic fallout deposits have commonly been classified into end-member types based on dispersal patterns and deposit grain-size characteristics. These deposit types have then been related to relatively simple end-member explosive eruption styles including aspects such as plume height, explosive fragmentation intensity, external water and magma explosive interaction. More recently attempts have been made to relate juvenile pyroclast vesicularity to the standard eruption styles. Although the dispersal and grain-size characteristic approaches are valuable for young fallout deposits whose original extent is still well preserved, there are many limitations in applying these approaches to older, variably eroded deposits. For these, the facies aspect or deposit characteristics at remaining, isolated outcrops are commonly used to infer the general eruption style. However, many recent explosive eruptions have demonstrated that explosive fallout forming eruptions can be very complex, pulsing from one eruption style to another or having characteristics of more than one style simultaneously, such as Etna, with simultaneous Hawaiian and micro-plinian styles. Can these multiple, simultaneous eruption styles be detected in the characteristics of the deposits, and can the deposits be distinguished from those of simple end-member eruption styles? Some explosive fallout deposit forming eruptions also experience multiple intraplinian column collapse events that produce pyroclastic flow deposits, apparently at the same time as fallout deposits continue to form, such as Pinatubo, Philippines, Fogo A, Azores. Are there distinctive differences between the fallout deposits before and after the collapses, should they be treated as discrete separate fallout events and deposits, or do they just represent an ongoing continuum of the one fallout forming event?

There are many complications in the eruptions that produce fallout deposits and these are not adequately represented in the current approach to classification. The aim of this symposium therefore is to invite presentations on the characteristics of fallout deposit forming explosive eruptions, the complexities that can occur in the eruption styles, how we recognize these complexities in the deposits, new approaches that can be used to study fallout deposits as a basis for classifying them and understanding the eruption styles, and the limitations of traditional approaches.

Explosive volcanic eruptions: from observations to quantification

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Eruptive styles can vary significantly based on several factors including magma composition, volatile content, magma feeding rate, tectonic setting and presence of external water. More than for the need to label volcanic eruptions, the importance of classification builds on the necessity of understanding volcanic processes through the identification and analysis of common features of eruptions having similar characteristics. Early classifications and terminology were mainly based on visual observations of eruptive phenomena at specific volcanoes and eventually evolved to take into account deposit features. In particular, Walker (1973, 1980) proposed a classification based on the analysis of tephra deposits and introduced five parameters for the estimation of the scale of explosive eruptions: i) magnitude, ii) intensity, iii) dispersive power (related to the total area of dispersal and, therefore, to plume height), iv) violence (related to kinetic energy), v) destructive potential. Even later classification schemes are based on parameters which are somehow related to these five kinds of bigness.

Out of all these parameters, the relation between magnitude and dispersive power (i.e., plume height) remains controversial. In fact, even though the Volcanic Explosivity Index (Newhall and Self, 1983) assumes a correlation between magnitude and intensity, the two parameters seem unrelated, especially for unsteady and effusive activity, with an eruption of small magnitude being able to have a high dispersive power if characterized by a high plume. This already highlights some of the shortcomings of current classification schemes that fail to well describe small to moderate explosive eruptions. In addition, many eruptions show hybrid features and could start with an eruptive style and terminate with a different activity resulting in a complex stratigraphic record difficult to classify. Finally, some small eruptions would be better described based on the analysis of all volcanic products and not only of tephra deposits (e.g. voume ratio between erupted lava and tephra).

Progress in physical volcanology and the increase capability of monitoring explosive eruptions have highlighted how a comprehensive classification should combine deposit features together with geophysical observations, with deposit features including deposit thinning, deposit grainsize, textural features, componentry, and both density and porosity of products. The development of a comprehensive classification scheme that can cover the whole range from weak explosions to ultraplinian eruptions presents one of the main challenges for the future. Regardless of the classification scheme considered, it is also very important to quantitatively characterize the uncertainty associated with the parameters used. The description of such uncertainty is crucial to any hazard assessment and evaluation of future eruptions at any given volcano.

From field data to volumes: constraining uncertainty for pyroclastic eruptions

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In this study we aim to understand the variability in eruption volume estimates from field studies of pyroclastic deposits. Variability arises from three components: site selection in the field, hand-contouring of thickness measurements, and the selection of methods to integrate data and estimate volume. We distributed paper maps of the 1959 Kilauea Iki tephra dataset to 101 volcanologists worldwide, who produced hand-drawn contours. The returned isopach maps show great variety in contour number, spacing and shape. More experienced participants tended towards fewer, smoother, and more elliptical contours. However, these differences do not manifest in differences in isopach areas for a given thickness value. After excluding outliers we find that isopach area uncertainty lies around 7% across the well sampled deposit, but increases to over 30% for isopachs that are associated with the largest and smallest thickness measurements, where there is more uncertainty with the field data and hence more subjectivity. We fit exponential, power-law and Weibull functions through the isopach thickness versus square root area values and find an average standard deviation for total volume of s = 37%. The volume uncertainty is again largest (s = 58% to 59%) for the most proximal field that is not constrained by measurements and the distal field for which measurements are strongly affected by post-depositional processes, while uncertainty across the densely sampled deposit lies at s = 8%. In case of the Kilauea Iki 1959 eruption we find that the deposit beyond the 5 cm contour line contains only 1% of the total eruption volume, while the extrapolated near-source deposit contains 61% and the well-constrained intermediate deposit 38% of the total volume. Thus the relative uncertainty within each zone impacts total volume estimates differently. The large uncertainties in distal and proximal field are associated with the extrapolation of the empirical functions, and we expect uncertainty for different eruptions and eruption types to show similar uncertainty trends. Therefore, we suggest a new convention of stating all three partial volume estimates: one for the deposit that is constrained by measurements extending to the largest and smallest reasonable isopach, one for the extrapolated deposit above the thickest isopach and one for the extrapolated distal deposit beyond the thinnest contour. This convention allows third parties to better assess the associated uncertainty of an eruption volume, and is also a useful tool to identify desired measurement locations during a field campaign in order to improve the accuracy of volume estimate of a given deposit.

Emplacement of complex fall deposits from heterogeneous magmatic systems: the bimodal Cuicuiltic member at Los Humeros caldera, Mexico

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The Cuicuiltic Member of Los Humeros Caldera, in the eastern Mexican Volcanic Belt is a Holocene, ca. 6 m thick fallout deposit formed by alternated layers of trachydacite and basaltic-andesite pumice and scoriae that record the youngest explosive activity from the caldera. It has been subdivided in nine units (C1 to C9) according to its textural and chemical characteristics. The distribution of its internal units is varied across the caldera; felsic layers dispersal is almost radially from the center, whilst the mafic units are clearly from the SE and NE sectors. The Cuicuiltic eruption was fed primarily from one central vent and subsequently from at least three independent but simultaneously active basaltic vents located few kilometers apart. The eruption began with a trachydacite explosive phase depositing pristine gray pumice in the center of the caldera (C1 and C2), followed by short period of mixing accompanied by basaltic andesite pumice (C3). After a short repose period, at least two andesitic to basaltic fissure vents went off ejecting pumice and scoria along a weakness structural plane, parallel to the nested Potreros caldera scarp (C4 and C6). These eruptions turned less energetic with time until reaching Strombolian style. However, trachydacite pumice (C5) erupted in between the basaltic-andesite scoriae and kept falling intermittently accompanied by mingling (banded pumice-bearing layer C7). Simultaneous activity from the central felsic vent and local basaltic episodes deposited layer C8. The end of the eruption is marked by deposition of a pumice layer from a probably hybridized magma chamber. Preliminary studies evidence a heterogeneously zoned magma reservoir with two high-melt zones, one trachydacite and the other a discrete basaltic, both interacting at some point during the eruption. This unusual type of bimodal and coeval volcanism has been little documented. However, the phenomenon is probably more common than what expected, but unfortunately pristine exposures, contrasting compositions and detailed stratigraphic sections are necessary to document such changes within a paleosol-bounded eruptive unit. The nearly simultaneous eruption or in short succession, of magmas of contrasting composition reveals the complexity of the magmatic system. The significance of recognizing the multiple vent nature for this eruption translates on a much better understanding of the Los Humeros magmatic behavior over time and remarks the importance of thoughtful field relations when studying complex fall deposits from caldera volcanoes.

Stratigraphy and eruptive dynamics of the 2011 Cordon Caulle eruption, Chile

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The Puyehue Cordon Caulle volcanic complex, Central Andes Southern Volcanic Zone, Chile, erupted on June 4th, 2011, after 41 years of repose, from a single vent along the Cordon Caulle fissure system. This system generated at least 5 historic eruptions. The 2011 eruption started with a 10 to 12 km high plume that dispersed most of the tephra towards E and SE by strong winds. The wind shifted towards NE on June 6th and again towards E on June 7th and plume height was between 8 and 10 km. After this initial paroxysmal phase, the activity continued during several months as low level ash emissions (4 to 8 km). Pyroclastic density currents were generated on 5 to 8 June and affected the Nilahue river valley. Lahars damaged the international road and destroyed a bridge in the Nilahue river. On June 20th lava effusion was reported, which lasted until April 2012.
Tephra fallout affected a wide area, including Neuquen, Rio Negro and Chubut provinces in the west part of Argentina and even reaching the Central part of Argentina, Uruguay and Southern Brasil. The eruption significantly impacted both the local and regional economy and caused the evacuation of 3500 people in Chile. Air traffic was disrupted in Argentina with a massive cancelation of national and international flights and the temporary closure of several Patagonian airports. Land and water transportation, water and electricity supplies and telephone communications were significantly affected. Several field surveys were carried out between June 2011 and February 2013. Eruption stratigraphy was characterized based on about 70 outcrops identified between the vent area and 250 km E from the active vent, along the main dispersal axes that characterize the initial paroxysmal phase of the eruption. Various fallout units were identified in the field within the tephra sequence, each characterized by grainsize, componentry and density analyses. Each unit was related to the chronology of the eruption based on ash dispersal as described by satellite images and observed tephra deposits. Volume, total grain size and mass eruption rates associated with the main tephra units were also derived.

Reconstruction of eruption dynamics and conduit evolution from granulometry, componentry, and accessory lithic clast morphology: the 2360 BP eruption of Mount Meager

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The Mount Meager Volcanic Complex in SW British Columbia is the source of the most recent (2360 BP) explosive eruption in Canada. The initial subplinian phase of the eruption produced an extensive, unconsolidated, pumiceous pyroclastic fallout deposit that is mainly distributed NE of the vent. The fallout was deposited on terrain characterized by mountainous topography and steep-sided river channels, resulting in intricate complexities within the deposit. Unlike archetypical fall deposits, the 2360 BP fallout exhibits irregularities in the thickness of the deposit, thickening into the steep valleys and thinning over topographic highs, and is commonly capped by remobilized or resedimented pumiceous fallout material.

Here, we present detailed stratigraphy, granulometry and componentry data for the fallout deposits, which reveal notable cryptostratigraphic trends. In addition to the local variations in deposit thickness due to topography, detailed stratigraphy reveals additional complexity relating to the aerial location of the deposit and its source, either from the edge or core of the eruption plume. Granulometry results indicate a total of five distinct phases within the central zone of the fallout deposit (oriented ENE from the vent), while the margins of the fallout deposit feature no distinguishable variations in grain size. Componentry results show that within the juvenile material, the primary trend is a gradual increase in the abundance of gray and banded pumice, relative to the dominant white pumice, with increasing stratigraphic height. This indicates a change in magma properties as the eruption progressed. Particular attention was also paid to the accessory lithic componentry within these deposits. The most notable trend is a gradual increase in the abundance of monzogranite accessory lithics. The source of these monzogranite lithics is the Miocene Fall Creek Stock, the upper contact of which is located approximately 700 m below the vent. Thus, the increase in monzogranite lithics with increasing stratigraphic height suggests a deepening of the fragmentation front as the eruption progressed.

Morphological analyses of accessory lithics present in the fallout deposits were also performed. These analyses revealed notable correlations between lithic source depth and the overall degree of rounding, and between lithic size and the degree of rounding observed.

Detailed stratigraphic analysis and traditional granulometry and componentry data of the 2360 BP Mount Meager fallout deposits indicate fluctuating eruption conditions, expressed by a deepening of the fragmentation front and change in magma properties during the course of the eruption. A more turbulent or dynamic plume core resulted in increased complexities within the centre of the deposits compared to the margins. The results presented here promise to enhance our overall understanding of pyroclastic fallout deposits and how to interpret the information embedded within them.

Reconstruction of volcanic plume dynamics and fallout deposits on the basis of numerical simulations

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During an explosive volcanic eruption, volcanic gas and ash are ejected from the volcanic vent. Depending on terminal velocity, the particles (i.e., volcanic ash) are carried up within a convective plume, are advected by the surrounding wind, and sediment on the ground. The fine particles are expected to have atmospheric residence, whereas the coarser particles form ash-fall deposit. Recently, particle-tracking models such as PUFF and advection-diffusion models such as TEPHRA2 and FALL3D tried to forecast both particle concentration in the atmosphere and particle loading at ground level. In these models, the source conditions (the plume height, and mass release level) should be given on the basis of a simplified model of bent-over plume (e.g., Bursik, GRL 2001) which contains an empirical constant (entrainment coefficient related to the wind-caused entrainment, β). In order to determine the value of the parameter (i.e., β) and the other source conditions for tephra dispersion, we are developing a 3-D numerical model which reproduces the dynamics of convective plume, the ash transport, and fallout deposits.

The model is designed to simulate the injection of a mixture of solid pyroclasts and volcanic gas from a circular vent above a flat surface in a stratified atmosphere, using a combination of a pseudo-gas model for fluid motion and a Lagrangian model for particle motion. During fluid dynamics calculations, we ignore the separation of solid pyroclasts from the eruption cloud, treating an eruption cloud as a single gas with a density calculated using a mixing ratio between ejected material and entrained air (Suzuki et al., JGR 2005). In order to calculate the location and movement of ash particles, we employ Lagrangian marker particles of various sizes and densities. The marker particles are ejected from the vent with the same velocity of the eruption cloud every 10 sec. The particles are accelerated or decelerated by the drag force on the spheres and fall to the ground with their terminal velocities.

We carried out a series of simulations of a small-scale eruption in various wind fields with the magma discharge rate of 2.5 x 10^6 kg/s, the initial temperature of 1000 K, and volatile content of 2.84 wt.%. The simulation results show that as the wind speed increases the mass of the entrained air increases and the plume height decreases. Through comparisons between the present results and the 1-D model predictions, we found that the preferable value of β (0.2-0.3) is substantially smaller than those suggested in previous works (0.3-1.0). The simulation results also indicate that (1) the main mass release level of particles is lower than the total height of plume, and that (2) it depends on the particle size. We confirmed that the present model correctly reproduces the plume height and ash fall area during the 2011 Shinmoe-dake eruptions (Suzuki and Koyaguchi, AGU2012).

The application of statistical methods in determining volcanic eruption parameters from tephra fall deposits

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An important methodology in determining eruption parameters for historic explosive eruptions is inversion of the properties of tephra fall deposits. We present a range of statistical approaches for determining the uncertainty that is inherent in these methods, in particular focussing on the estimation of erupted volume and eruption column height. We also use statistical tools to make a more general exploration of which areas of a tephra fall deposit contain the most information about the overall deposit structure and the eruption that formed it.

Eruption volume is typically determined by extrapolating thinning trends found from isopach maps drawn for the areas of the deposits that are preserved, a process that can be subjective and variable. We have developed an alternative statistical method to objectively determine the volume of a fall deposit without the production of isopach maps, in which integration of a log-linear regression model for thickness measurements with distance from the vent is applied to the field measurements without any prior interpretation, and data and model uncertainty is accounted for using Bayesian methods. We find that eruption volumes calculated using our method correspond well to those previously determined by alternative approaches for eruptions including Fogo A, Askja D, Pinatubo C1 and Santa Maria 1902.

Eruption column height and windspeed during the eruption can be inferred from measurements of the maximum clast size found at a given distance from the vent. We have used probabilistic, maximum likelihood techniques to determine which of the methods typically used in the field to determine maximum clast size best reconstructs known eruptive conditions. We have simulated the Grain Size Distribution (GSD) of fall deposits for a known volumetric flow rates, and perform inversions on maximum clast sizes from these statistically-produced GSDs at multiple locations to determine the volumetric flow rate and confidence interval. Comparison of modelled volumetric flow rate with the 'known' volumetric flow rate is then used to identify which method for determining maximum clast size gives the most accurate interpretation of eruptive parameters. Confidence intervals for the accuracy of each method will be presented.

The number and distribution of thickness and maximum clast measurements from fall deposits can limit the amount of information gained from the deposit. We have applied a fixed point variogram to field measurements to identify the dependence of the structure of a deposit (referenced to vent location) to different spatial distributions of measurements. Results suggest that measurements from medial and off-axis areas of the deposit are the most informative.

Which part of the eruption cloud does volcanic ash fall from? An inversion analysis of the 1986B Izu-Oshima eruption

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Eruption clouds are the source of volcanic ash. Although several physical models of eruption clouds have been developed during the last three decades, and many reconstructions of ancient eruption clouds based on tephra dispersal have been attempted, the mode of particle release from eruption clouds remains unclear. Current tephra fall simulations assume a simple model, such as uniform release from entire span of an eruption column. Since wind direction and the downwind flow differ depending on altitude, the mode of particle release as a function of height greatly changes ash dispersal. The accuracy of tephra fall simulation thus significantly depends on mode of particle release from the column.

The 1986B Izu-Oshima eruption was sub-plinian and formed a vertical eruption column up to 13km high. Based on data of ash mass loading in tens of localities in downwind area and calculation using Tephra2, an advection-diffusion tephra fall simulation code, we obtained quantitative change of particle release as a function of height.

We calculated particle contribution of every 1-km height interval of the eruption column (i) to each locality (j) using Tephra2. Wind data at the eruption time was based on a re-analysis data, JRA-25. The contribution is calculated using Tephra2 for each size class (phi) and expressed as cij(phi). The mass loading at the locality sci(phi) is calculated cij(phi)ri(phi), where ri(phi) is released particle mass from height interval i. The ri(phi) is obtained by grid-search to minimize evaluation function E changing ri(phi) in appropriate range. The evaluation function adopted here is expressed as E = log(sci/ soi), where soi is ash mass loading measured in the field.

Our result indicates bimodal particle release as a function of height. All available particle sizes (2 to -5phi) show that the most significant particle release took place at around 2 to 3 km above the vent and up to 90% of detected erupted mass left in this lower part of the column. The -2 and -3phi particles also have significant particle release at around 6 to 7 km above vent and approximately 20% of these fractions are released in this higher part of the column. The release of larger particles (<-3phi) in the higher part is limited to up to several percent. Particle release in the middle part of the column seems to have been limited. Smaller particles (>-2phi) have no resolution in the higher part because these particles are assumed to fall beyond the island's coast.

These results support the conventional theory that predicts particle release took place from uppermost part of the column, where an eruption cloud spread laterally. The results also indicate substantial particle release from the lower part of the column, confirming the importance of fallout from this region in estimating total eruption volume and in understanding column dynamics.

Inception of mafic, explosive caldera-forming eruptions: the basal fallout deposits of the "villa venni" (355 ka) and "pozzolane nere" (407 ka) eruptions at "colli albani" volcano (italy)

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The Villa Senni Formation (VSN; 355ka, 30 km3 DRE) and the Pozzolane Nere (PNR; 407 ka; 15 km3 DRE) represent the youngest of seven large explosive caldera-forming eruptions of the Colli Albani volcano near Rome, Italy. Both eruption units are characterised by very undersaturated, tephritic to tephri-phonolitic magma compositions and represent a mafic end-member of the spectrum of explosive caldera-forming chemical compositions. Both VSN and PNR eruptions produced a basal sequence of scoria-fall deposits, dispersed mainly to the east and overlain by their main ignimbrites. The minimum area encompassed by the preserved 20 cm isopach line is >500 km2, which indicates a much larger original total dispersal area, and allows the classification of these deposits as Plinian fall deposits.

Petrologic analyses of each fall deposit were performed by a combination of SEM and microprobe techniques. The internal textures and structures of the scoria clasts were analysed to assess the effects of vesicles and microlites on the eruptive style and history. Results from the Vesicle Size Distributions for the PN suggest an uneven distribution of nucleation events. Vesicle Number Densities (VNDs) decrease upward from 10^9 cm-3 at the base to 10^8 cm-3 and increase again to 10^9 cm-3 at the top of the fallout sequence. These values are higher than those reported for mafic explosive eruptions and are more comparable to VNDs in tephra from silicic explosive eruptions. Vesicle Size Distributions for the VSN show lower values more typical of mafic explosive scoria. SEM analysis indicates that magma-water interaction is an important component of the initial fallout phase in both eruptions which, along with textural data, implies that decompression is a key factor for the explosive evolution of mafic eruptions.

Tephra in Argentina establishes postglacial eruptive history of Laguna del Maule volcanic field in Chile

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The Laguna del Maule (LdM) volcanic field covers 500 km2 of rugged glaciated terrain with Quaternary lavas and tuffs on both sides of the Argentina-Chile border in the Southern Volcanic Zone. At least 130 separate vents erupted >350 km3 of products since 1.5 Ma (Hildreth et al., 2010). These include a ring of 36 postglacial rhyolite and rhyodacite coulees and domes that erupted from 24 separate vents and encircle the lake, suggesting persistence of a large magma reservoir. The young, glassy, and largely non-overlapping lavas are difficult to date by 40Ar/39Ar. But whole-pumice and microprobe chemistry of downwind fallout in Argentina, and radiocarbon dating of intercalated soils, establish eruptive stratigraphy and timing of events for the postglacial eruptions at Chilean vents around Laguna del Maule.

A tri-country collaboration among the geological surveys of the United States. Chile, and Argentina, have now established that a wide area east of the volcanic field was blanketed by at least 3 plinian explosive eruptions from LdM sources, and by at least 3 more modest, but still significant, eruptions. In addition, an ignimbrite from the LdM Barrancas vent complex on the border near the SE corner of the lake traveled at least 15 km from source and now makes up a pyroclastic mesa at least 40 m thick. This ignimbrite (72-75% SiO2) preceded a series of fall deposits that are correlated with eruption of several lava flows that built the Barrancas complex.

Recent 14C dates suggest that most of the preserved LdM fallout eruptions were between 7 ka and 3 ka. However, the oldest and perhaps largest fall unit yet recognized is correlated with the Los Espejos rhyolite lava flow that dammed the lake and yields a 40Ar/39Ar age of 19 ka and a (calibrated) radiocarbon age of 14 ka. Pumice clasts as large as 8.5 cm and lithics to 4 cm were measured 32 km ENE of source. It is the only high-silica rhyolite (75.5-76% SiO2) fall layer yet found, correlates chemically with the Los Espejos rhyolite lava flow, and includes distinctive olivine-bearing lithics that are correlated with mafic lavas which underlie the Espejos vent. Extremely frothy pumice found near the vent is also consistent with the bubble-wall shards and reticulite pumice distinctive of the correlative fall deposit.

Another large rhyolite fall deposit (74.5% SiO2), 4 m thick 22 km E of source, has pumice clasts to 9.5 cm and includes ubiquitous coherent clasts of fine, dense soil that suggests it erupted through wet ground; 14C dates (uncalibrated) yield ages <7 ka. Stratigraphic details suggest that pulses of fallout were accompanied by small pyroclastic flows. Ongoing field and lab work continues to build the LdM postglacial eruptive story. The numerous postglacial explosive eruptions from the LdM field are of significant concern because of ongoing 30 cm/year uplift along the western lakeshore, as measured by InSAR.

Stratigraphic variation in characteristics of pyroclastic deposits in the 2011 subplinian eruptions of Shinmoedake volcano

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In general, a stratigraphic variation in characteristics of size distributions of pyroclastic deposits may reflect temporal behavior of eruption intensity. However, there is no quantitatively established methodology to link the stratigraphic variation and the temporal behavior of eruption intensity because of the complex coupling of several processes: eruption column dynamics, fallout process, and sedimentation. In case of old eruption's deposits, there is no detail such as accurate eruption evolution because they were not monitored at that time, and erosion process disguises the original stratigraphic variation. Fortunately, we have a chance, namely three subplinian phases of the 2011 Sinmoedake eruption, Kirishima volcanos, which promise the minimum influence of loss of fine materials. Furthermore different sources of observations concerning the eruption evolution by satellite images can be available in order to give additional constraints. This opportunity allows us to observe original stratigraphic variations of pyroclastic deposits and to compare our results and the other observations.

We collected samples at three localities, Takachihogawara (Tg; about 2 km far from vent), Miike elementary school (Mk; about 7.5 km far from vent), and Natsuo elementary school (Nt; about 11 km far from vent). In order to observe the temporal change of deposits, we divided the whole deposit into several to ten layers in sampling. We conducted grain size analysis for each layers by using sieves and the statistical analysis for obtained grain size distribution based on Inman (1952). As a result, characteristics of stratigraphic variation of grain size distribution in terms of median or mean show two peaks at Tg and Mk, and one peak at Nt. At all localities, peak positions of median or mean in the whole deposits are almost same, but totally these values shift finer with distance from the vent. Values of variance are nearly same at any distance and stratigraphic height.

Assuming that a single plinian eruption makes a single peak of median or mean of grain size distribution, analyzed deposits correspond to two subplinian eruptions. Together with isopach data by AIST (The National Institute of Advanced Industrial Science and Technology) and satellite image (Meteorological Agency), we conclude that the pyroclastic deposits at the sampling localities correspond to two plinian eruptions of 26th (16:10-18:35) and 27th (02:10-04:40). Furthermore the variation of a single eruption is also observed; first the values of median and mean become coarser, and then they become finer.

To explain the stratigraphic variation of grain size distribution of pyroclastic deposits, we formulate a model which relates the size distribution function as function of height at deposits, to initial size distribution and sorting process during settling. We will consider the cause of variation of median or mean and the relationship with eruption column dynamics and transportation in future.

Water-settled fall deposits from low to moderate intensity silicic submarine eruptions

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Submarine explosive eruption columns involving silicic magma are prone to collapse as the ejecta (hot pumice clasts and volcanic gas) mixes with the sea water, causing quenching and rapid increases in column density. However, low to moderate intensity silicic eruptions can generate water-settled fall deposits when pumice clasts are either (1) coarse (6-100 cm) clasts that are relatively slow to cool, or (2) lapilli that are erupted with near neutral to negative buoyancy. Both of these characteristics in combination with the low to moderate intensity, pulsatory eruption style promote deposition by submarine water-settled fall.

On Yali, eastern Aegean, Greece, a submarine pumice cone >150 m high, >1200 m radius has been uplifted. It comprises well sorted, essentially fines-free interbedded pumice lapilli facies and pumice block facies. Pumice clasts settled from suspension (coarse clasts) and showers (lapilli) and once deposited, were prone to syn- and post-eruptive resedimentation in modified grain flows, due to the steep flanks of the cone. We use the vesicle microtextures to track magma degassing and ascent in the conduit and to infer open-vent explosive fragmentation. Periods of low eruption intensity were critical in generating moderately vesicular pumice lapilli (45-60 vol.% vesicles) that were either negatively or neutrally buoyant. These lapilli fragmented primarily as a result of water interacting with the vesiculating magma. Lapilli in the lowest unit have weakly developed vesicle collapse textures and melt corrected vesicle number densities (Nmv) of 1.4 x 108 to 2 x 108 cm-3, suggesting that magma ascent slowed in the conduit. These moderately vesicular lapilli formed showers of pyroclasts that rained down close to the vent, forming thick proximal deposits. The coarse clasts and fragments derived from them are highly vesicular (65-80 vol.% vesicles) with relatively high melt-corrected vesicle number densities (Nmv) of 2.5 x 108 to 1.2 x 109 cm-3, suggesting magmatic-volatile-driven eruption at higher intensity rather than the previous interpretation of dome spalling (Allen and McPhie 2000). These coarse clasts remained hot and buoyant for several minutes after eruption and rose through the water column in a buoyant plume of heated water; they may have reached the sea surface before cooling and sinking.

Relatively small ejecta volumes (much less than 1 km^3) and low to moderate intensity pulsatory eruption style precluded formation of a steady column.

Allen SR, McPhie J (2000) Water-settling and resedimentation of submarine rhyolitic pumice at Yali, eastern Aegean, Greece. J Volcanol Geotherm Res 95:285-307

Cores for concern: The difficulty of recording tephra fallout deposits in marine sediments

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Detailed knowledge of the past history of an active volcano is crucial for the prediction of the timing and frequency future eruptions, and identification of potentially at risk areas. Studies of subaerial volcanic stratigraphies are often incomplete, due to a lack of exposure, or burial and erosion from subsequent eruptions. However, as a large proportion of volcanic deposits are deposited in the sea, cores of marine sediment have the potential to provide a more complete stratigraphic record of tephra fallout deposits. Nevertheless, problems such as bioturbation and dispersal by currents persist in the preservation and subsequent detection of marine tephras. Consequently, cryptotephras, which are invisible to the naked eye, may be the only record of pyroclastic fallout in the marine record. Additionally, thin, reworked volcanic deposits transported by floods and landslides are often interpreted as primary tephra fallout deposits, leading to the construction of inaccurate records of volcanism. This work uses the volcanic island of Montserrat as a case study to test novel techniques developed to generate volcanic eruption records from marine sediment cores. We outline a set of time-efficient, non-destructive and high-spatial-resolution analyses (e.g. XRF core-scanning and magnetic susceptibility) that can be used to effectively detect potential cryptotephra horizons in marine sediment cores. Following these, sampling of these potential tephras horizons for microscope analysis should be employed to discriminate between primary and reworked volcanic deposits. Our method involves using specific criteria related to clast morphology, compositional maturity, sorting and sedimentological facies indicators to determine primary from reworked deposits. As a result of these procedures, more individual tephra fallout deposits have been recognised around Montserrat in our study, than previous marine tephrochronological studies in this region. We suggest that standard practice be employed when analysing marine sediment cores to determine both visible and cryptotephra layers and ascertain primary and secondary volcaniclastic deposits.

Is tephra stratigraphy in seasonal snow likely to be preserved? Observations from proximal deposits at Fimmvorduhals (2010) and Tolbachinsky Dol (2012-13)

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Recent and ongoing eruptions have provided new opportunities for observing interactions between basaltic lava flows and snow: the 2010 eruption at Fimmvorduhals, Iceland, and the ongoing (as of 13 Feb) eruption at Tolbachinsky Dol, Kamchatka, Russia. Fieldbased observations highlight many similarities but also differences, which result in part from variations in pre eruptive snow conditions.

The 2010 Eyjafjallajokull eruption began on 20 March with the opening of a small fissure at the northern end of Fimmvorduhals, a pass separating Eyjafjallajokull to the west and Myrdalsjokull to the east. Eruption initiation produced local bomb and tephra deposits surrounding the vents and extending to the south, west and northwest of the vents. Two months after the end of the eruption we observed raised mounds in tephra immediately south of Magni cone at Fimmvorduhals. A small subset of the estimated more than 1000 observed mounds were measured and dissected in 2010 and 2011. The mounds vary in diameter from 0.5 to 1 m, and in height from 5 to 25 cm. We have tentative identified three developmental stages including: 1) incipient, 2) fractured, and 3) burst. The mound cores either contain a volcanic bomb at their core, or have formed over large boulders that were part of the pre-eruption landscape. Both types of cores are covered in turn by course basaltic tephra and fine trachyandesite tephra. We believe that, unlike typical dirt cones found on bare ice surfaces of glaciations, the bomb/boulder-cored tephra mounds (BCTMs) form by melting of snow deposited syn-eruption. Snow melting causes compaction of the overlying tephra, which accentuates tephra draping over the core stones. Likely critical for the formation of the mounds is the covering layer of finer-grained, more cohesive trachyandesite tephra, which was deposited in mid-April after the eruption shifted from Fimmvorduhals to the summit of Eyjafjallajokull. It is unlikely that this unique sequence of events is common, and the mounds likely have a low preservation potential. However, they preserve a record of eruption during winter months when snow can accumulate during less vigorous periods of eruption, and something closely akin to BCTMs might form on planets like Mars when lava domes are emplaced into permafrost that is later covered by fine-grained dust.

Tephra pits dug in snow during January 2013 show a complex tephra-snow stratigraphy within 2 km of the active vents at Tolbachinsky Dol. The main pit, 2.5 m in depth, exposed four main layers of coarse ash and lapilli separated by variable thicknesses of snow. The pit shows that some snow was present before the start of the eruption, and tracks the interaction between environment (snow accumulation and/or wind direction) and eruption dynamics (changes in intensity of eruption). We will be revisiting this site during summer 2013 to determine what happens to the tephra-snow stratigraphy during summer snowmelt.

The relationship between magmatic-phreatomagmatic transition and vesicularity in Heian eruption of Towada Volcano

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The occurrence of phreatomagmatic eruption is considered to be controled by mass ratio of external water and magma (Wohletz and McQueen,1984). However, on felsic explosive erup-tion, magma is in already vesiculated and fragmented before contacting with water, and it seems to be one of the controlling factors on eruptive style through the difference of contact surface area (Yamamoto,1989). This study examines the factor causing the transition from magmatic to phreatomagmatic eruption other than magma-water ratio.

Heian eruption at Towada volcano began with magmatic eruption, thereafter repeated magmatic and phreatomagmatic alternately. Through this activity the vent was in caldera lake (Kudo,2010) and the magma always contacted with water.

From the steadiness of grain size distribution with time, the first plinian phase (pumice fall: unit OYU-1) kept constant magma discharge rate, and magma-water ratio can be regarded as constant (Koyaguchi and Woods,1996). Following few hours, the eruption proceeded to phreatomagmatic one rapidly (base surge: unit OYU-2).

Phreatoplinian eruption produces extremely fine-grained ash deposit (Self and Sparks,1978) mostly consisting of plate-like shards originated from large expanded bubble wall (Heiken and Wohletz,1985). Because external water hinderes bubble growth by rapid cooling, bubbles should grow before contacting with external water. We classified glass shards into large expanded bubble group and small bubble group, and proved successive bub-ble growth through OYU-1 and OYU-2 stages.

Pumice clast from magmatic eruption has low density than that from phreatomagmatic one (Walker,1981;Heiken and Wohletz,1985), that is in harmony with the density measurements for pumices of Heian eruption, but seems to be in conflict with vesicularity expected from the degree of bubble growth derived from glass shards analysis. This implies vesicularity differ-ence occurrs after the magma-water contact.

Since the surface of pumice should hold their texture at fragmentation, we focused on their bubbly and foamy portions ratio to investigate the difference of bubble portion on pumice surface. Contrary to the shards, however, their increase is not successive throughout but de-creased temporarily at the transition from OYU-1 to OYU-2. It may be the result of superpo-sition of additional vesiculation on inherent vesicularity increase with time on OYU-1 unlike pumice surface.

Fine-grained shards hold the information at fragmentation, but pumice on phreatomagmatic eruption freezes its texture immediately before magma-water contact rather than at fragmen-tation, and pumice on magmatic eruption may loose both of them to some degree by further vesiculation after the ejection.

The increase of large expanded bubble, suggested by fine-grained shards analysis, is an important factor for the transition from magmatic to phreatomagmatic eruptions through the efficient heat transfer from magma to water by increasing contact surface.

Fragmentation mechanism of basaltic tephras from two far-reaching historical eruptions from Katla volcano, Iceland

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Do volcanic eruption plumes from Iceland pose a significant hazard to the European society? Yes is the obvious answer after the 2010 Eyjafjallajökull and 2011 Grimsvötn events. This has long been recognized from the deposits of silicic eruption plumes found all over Scandinavia and Great Britain. However, even more interestingly the Grimsvötn 2011 eruption also showed the world that the hazard potential of basaltic explosive eruptions from Iceland is significant.

Why are the basaltic explosive eruptions in Iceland so potent? Is it the sheer volume of basalt erupted at high eruption rates or has it to do with the ubiquitous glaciers on top of the central volcanoes? How much influence does melt water-magma interactions have on the fragmentation process of far-reaching basaltic eruption plumes from Iceland?

Here we present results from investigations of the basaltic Katla 1755 and 1625 eruption deposits. Katla is one of the glacier covered central volcanoes in the Eastern Volcanic Zone in Iceland. More than 300 basaltic and 20 silicic explosive eruptions are recorded from the Katla volcano in the Holocene time. Some of the silicic tephra layers are found in the European tephra record. Historical documents report that both of the studied tephra layers reached well outside of Icelandic borders. Mapping of the tephra has revealed that the layers from both events have an east-northeast directed thickness axis propagating from an eruption site within the caldera of Katla. The duration of the two Katla eruptions have been documented by historical records as 120 days for the 1755 eruption and 13 days for the 1625 eruption, respectively.

The two tephra layers were sampled and described at median to distal localities with special emphasis on the fine portion of the deposits. The grain size distributions were obtained by hand sieving and the fine portion analysed with a SediGraph 5120 instrument. Special attention was given to the sample portion smaller than 125 microns and the grain morphology and shape parameters defined with Particle Insight Dynamic Image Analyser. Selected samples were then analysed by SEM. At the meeting we will present our results and discuss the role of glacier/melt water in magma fragmentation and fine tephra formation in these two eruptions. Further we will discuss the fragmentation mechanism's effect on the ability of tephra to be carried thousands of kilometers from source.

The 1732 phreatomagmatic eruption of Eggoeya, Jan Mayen.

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Jan Mayen is a volcanic island situated at 71 degrees N and 8 degrees W making it the northernmost active surface volcano in the world. The Island is build up of two main edifices, South Jan and North Jan (Beerenberg). Volcanic activity on the island is little known, however at least 5 eruptions are documented on the island since early 18th century.

Expeditions to the island in summer 2011 and 2012 reveal that the first of these eruptions formed the tuffcone Eggoeya in 1732 AD. The Eggoeya tuffcone is situated at the south-west foot of the Beerenberg volcano. The tuffcone, now partly eroded by the sea, is about 1.5 km in diameter and emerged from about 35 m depth to reach the altitude of at least 217 m above sea level. Pre Eggoeya lava flows on the coast north of the edifice are covered by up to 2,1 m of fallout and pyroclastic surge deposits some 2 km from the vent. These lava flows have previously been suggested to be formed in the 1732 eruption and the 1818 eruption of Jan Mayen. However, they are covered with the Eggoeya tephra and thus older than the 1732 eruption. Tephra from the Eggoeya eruption forms the uppermost tephra layer on most of Jan Mayen. Contemporary description of the 1732 eruptions tell of an explosive eruption at the foot of Beerenberg observed by German whalers from the 17th to 21st of May, when a change of wind allowed them to leave, but also covered their sails and decks in volcanic ash. A Dutch whaler group arriving to the island in June that year, report fine ash covering the island in such a way they sank up to mid leg into it.

Our study shows that the only eruption these descriptions fit is the Eggoeya eruption, dating it precisely to the spring 1732. The eruptive products are made up of vesicular tephrite-basanite to trachybasaltic glass groundmass and ol, px and fs crystals, in line with other primitive flank eruptions of Beerenberg. In this presentation we shall present the eruption chronology, glass chemistry, eruptive processes, emplacement mechanisms, distribution and volume calculation of the eruption.

Eruptive history of the barombi mbo maar, southwest cameroon, central Africa: constraints from tephrostratigraphic analysis of phreatomagmatic deposits

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The Barombi Mbo Maar (BMM), the largest maar in Cameroon, is located on the Cameroon Volcanic Line (CVL), 200Km SW of the Nyos Maar and 60Km NE of Mt Cameroon. It is surrounded by about 126m thick of pyroclastic materials on its eastern flank. For the first time, we have examined this thick pile of materials in detail. Three exposed tephra sections of the inner crater of the maar were inspected in order to reconstruct its eruptive evolution. Field studies regarding grain size, fabric, structures, clast morphology and abundance as well as transition style between different layers permitted to describe the layout of the deposits, discuss the depositional mechanism, the welding processes, and the main eruptive styles. Stratigraphically, three main depositional units subdivided into layers that we grouped into two cooling units are observed. From the bottom upwards, a thick unconsolidated to poorly consolidated series of thin lenticular and well stratified lapilli- and ash-beds is covered by a dry pyroclastic surge, loosely packed and very crumbly. This forms the most accessible part of the lower unit (U1). U1 is overlain by an explosive breccia and two dense and consolidated layers of lapillituff and lapillistone that constitute the second unit (U2). A thin (10cm) bed of paleosoil separates the first cooling unit (U1 + U2) from the second corresponding to the upper unit (U3). U3 consists of a complex and massive fallout deposits with 03 sub-units containing many explosive breccia layers full of basement rocks and mantle xenoliths. The sequence of eruptive activity corresponding to the stratigraphy of the deposits would be represented by: (1) phreatic and phreatomagmatic fragmentation that favoured the quarrying of the vent zone. This first volcanic episode would have been very explosive as suggested by the small sizes (2 to 10mm) of the clasts contained in U1 and the significant quantity (about 60 percent) of country rock fragments found in U2. Activities developed mostly in dry conditions as shown by the porous character of materials, and the absence of water evidence proof during transport as accretionary lapilli. At the end of this eruptive episode, a wet phreatomagmatic phase developed characterized by the welded and hardly consolidated upper part of U2, though temperature would have also played a significant role. (2) A series of hydromagmatic eruptions occurred to form U3 after a relatively long reposed period characterized by the presence of the paleosoil.

Two far-reaching historical eruptions from Katla volcano, Iceland: Fragmentation mechanism of the basaltic tephras

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The role of magma mixing in the explosive 2007-2008 eruption of Oldoinyo Lengai, Tanzania

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Oldoinyo Lengai in northern Tanzania is best known for its natrocarbonatitic effusive activity, alternating with highly explosive eruptions. The most recent explosive eruption which terminated 25 years of mildly explosive to effusive natrocarbonatitic activity started on the night between September 3rd and 4th 2007 and lasted until April 2008.

We sampled tephra fallout on September 7th 2007 (i.e. three days after the onset of the eruption), on September 24th 2007 and then later in May 2011, when we also measured the dominating grain size and overall thicknesses of tephra layers deposited at 140 locations around the volcano. At most locations three layers defined by variations in grain size could be identified, but on the western side of the volcano, where a larger amount of ash has been deposited (due to the overall wind direction from east to west), up to seven individual layers are present. All pyroclasts, independently of sampling location, are well-rounded with a core of euhedral silicate minerals (commonly nepheline, pyroxene, garnet or wollastonite), coated by a moderately vesiculated melt film.

From geochemistry, it is clear that the first tephra fall sampled on September 7th represents an incomplete mixing between a natrocarbonatitic and a nephelinitic magma. This tephra (sampled at three different locations) consists of variable amounts of silicate fragments, natrocarbonatite droplets and a mixture between the two magmas. Two weeks later (i.e., on 24th September 2007) the composition of this tephra is consistent with being a hybrid between a nephelinite and a natrocarbonatite. At this stage of the eruption, the natrocarbonatitic magma is completely assimilated into the new hybrid magma and components of the typical natrocarbonatitic composition can no longer be observed.

Geochemical data support mixing between natrocarbonatitic and nephelinitic magma: decreasing CO2 and alkali content with increasing SiO2 supports CO2 exsolution from natrocarbonatitic melt during mixing. The CO2 solubility is lower in the hybrid than in the natrocarbonatite, which thus leads to gas exsolution and bubble nucleation. We suggest that this forced exsolution of CO2 from the hybrid magma (in a crustal magma reservoir) is the driving force for the surprisingly explosive, mixed eruptions of Oldoinyo Lengai. The pyroclast shapes indicate that they were erupted in a similar way as an aerosol (i.e., as melt droplets carried by a gas stream), and that fragmentation may have occurred at depth within the conduit of the volcano when the gas volume-fraction was sufficiently high.

Characteristics of tephras from the initial stages of the eruption of Cordon Caulle Volcanic Complex eruption (Southern Andes), June 2011

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The Cordon Caulle Volcanic Complex (CCVC, 2236 m.a.s.l.), in the Southern Andes near the boundary between Chile and Argentina, is a large NW-SE-oriented volcanic chain (dated from late Pleistocene to Holocene). The Complex is the largest active geothermal area of the southern Andes located in a 6 x 13 Km wide volcano-tectonic depression. On June 4th, 2011, a large, long-lasting eruption was initiated, ejecting during the first week approx. 4x106 m3 of pyroclastic materials. Prevailing winds coming from the west dispersed ashes to the east affecting extensive areas in Argentina as far as 1300 km from the source volcano. Two months after the eruption, additional 2.5 x106 m3 of ashes had been accumulated affecting 7.5 x106 hectares in the countryside of Argentina. This contribution synthesizes the study of samples collected on a daily-basis during the first week of the eruption in different locations, both close and far away from the source volcano. A multidisciplinary physical-chemical approach is based on studies performed on particles size, morphology and chemical analyses, which were carried out with laser grain-size measurements, SEM-EDS microscopy and the XRD techniques. The obtained results allowed to recognize a complex tephra variability in the initial stages of the eruption.

From June 4th to 13th the eruption was characterized by episodic stages, and thereafter a relative stability was reached, according to the reports provided by SERNAGEOMIN (Chile). Following the beginning of the eruption, two events of column collapse were registered on June 5th and 13th respectively. On June 5th the eruption reached its higher intensity (VEI 5 = Plinian). The sampled tephras from CCVC collected in different Argentine localities during that period, are siliceous, mostly fine sand and silt/clay-sized with relatively high amounts of particles smaller than 4 micrometers in size, that correspond to the respirable fractions (up to 10 percent of the bulk sample in the nearby regions and higher as they are blown-out by wind). The chemical data indicate a basaltic and rhyolitic composition with trachyandesitic particles, observed in the near-source samples (Villa Angostura and Bariloche), whereas in distal localities are particularly rhyolitic (Buenos Aires and Puerto Madryn, located more than 1000 km East). Significant results have been also obtained on the short-term transformation of volcanic ashes. According to the performed chemical data, after June 7th the tendency of high silica ash content was increasing. Cristobalite (SiO_2 polymorph) was detected in the approx. 5 micrometers size-fraction of the studied samples from the initial days of the eruption. This, together with the relatively large amount of respirable fractions, made the first stages of this eruption highly hazardous to human health and environment.

Mafic minerals compositions as a useful tool for the identification of source volcano of weathered fallout deposits - a case study of the middle Pleistocene tephra beds in central Japan -

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The middle Pleistocene in the Chubu-Kanto district, central Japan; such as the Matsumoto, Ina basins, the Boso peninsula and so on, intercalate numerous fallout tephra beds. And a lot of Quaternary volcanoes are situated at the Chubu mountain range, central Japan. But it was difficult to identify source volcano of the middle Pleistocene tephra beds in the Chubu-Kanto district except a part of those tephra beds for their weathering and successive limitation. Therefore, this study try to identify their source volcano based on chemical compositions of mafic minerals as follow as hornblende and pyroxenes. Because of these minerals commonly occur in the Japanese middle Pleistocene tephra beds and are more strongly for weathering than volcanic glass in terrestrial deposits.

The middle Pleistocene tephra beds in the Chubu-Kanto district are described about their lithofacies and mafic mineral assemblage and analyzed chemical compositions of their mafic minerals. Chemical analyses for the mafic minerals from these tephra beds reveal that the hornblende and orthopyroxene compositions are distinguished depending to their source vents, i.e., the Older Ontake volcano (0.78-0.39Ma), Kurofuji volcano (1.00-0.50Ma), Tateyama volcano (0.22Ma-present), Suiendani source vent (0.40-0.33Ma) and so on. The activity of the Older Ontake volcano was divided into Tephra Stage (0.78-0.64Ma) and the Lava Stage (0.64-0.39 Ma) based on the mode of eruption. The tephra Stage is further subdivided into the three substrates namely H (around 0.78Ma), PH (0.78-0.70Ma), OP Substage (0.70-0.64Ma) on the basis of the assemblage of dominant mafic minerals in the air fall tephra. Age of each Stage and Substage were inferred from the stratigraphic relations with numerous dated lavas. Each Stages and Substages is distinguishable based on not only the mafic mineral assemblage but also the chemical compositions of hornblende phenocrysts in fallout tephra beds and lava flows. Conclusively, it was confirmed that the chemical compositions of these minerals, especially hornblende can be a useful criteria for identification of source volcano of the middle Pleistocene tephra beds, even in the highly weathered samples.

Effects of vertical diffusivity of particles on distribution of deposits calculated by the tephra-tracking model PUFF

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Understanding the process of tephra dispersion is scientifically important to estimate eruption conditions from tephra fallout deposits and also socially and economically required to prepare for risks of tephra-fall. For this reason, advection-diffusion models for tephra transportation have been developed with simplified assumptions (e.g., TEPHRA2). The final goal of this study is development of a new advection-diffusion model which correctly reproduces the physical process of tephra dispersion in the atmosphere.

In TEPHRA2 model, vertical diffusivity of particles is assumed to be negligible. Under this assumption, if the tephra particles of a single grain size are supplied from a point source in the atmosphere, the distribution of the diffused particles is described by a bivariate Gaussian distribution. When the particles with various sizes are released from different heights, the distribution of the entire tephra deposit can be expressed by a simple superposition of bivariate Gaussian distributions. This assumption makes analyses of geological data easier; however, its limitation should be carefully evaluated because the effect of vertical diffusivity on distribution of tephra deposit is not clear. In this study, we systematically investigated the effect using PUFF model.

In PUFF model, Lagrangian particles are advected with the local wind velocity and fall with their terminal velocities. The horizontal and vertical diffusions of particles due to atmospheric turbulence are simulated by random walk formulation. In our calculation, single-sized tephra particles are released from a point source above a vent and they are advected and diffused under a uniform wind condition.

In each run, the released particles diffuse and form a "particle cloud"; the size of cloud increases with time. Because horizontal diffusivity is set to be much larger than vertical diffusivity, the particle cloud has an oblate spheroid shape. The particle cloud moves horizontally with wind speed and fall to the surface at terminal velocity of particles. Because of the vertical extension of the particle clouds, the particles at the top of the cloud keep moving horizontally until their settlements, even when those at the bottom are deposited. As the result, the tephra particles are finally deposited in an area elongated and slightly widening toward downwind. To compare the particle distribution with a bivariate Gaussian distribution, variance, skewness and kurtosis of the particle distribution in parallel and cross wind direction are calculated. The particle distribution has larger variance, skewness and kurtosis in parallel wind direction, whereas larger kurtosis in cross wind direction.

The above results suggest that the vertical diffusivity plays an important role in the distribution of tephra fall deposits. The limitations of the bivariate Gaussian distribution assumption can be determined by the quantitative comparison with tephra deposits calculated with PUFF model.

Sub-plinian fall deposits and their grain size distribution of January 2011 eruption from Shinmoedake Volcano, Kirishima Volcanic Group, South Kyushu, Japan

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A series of sub-plinian eruptions occurred on 26-27th of January, 2011, from Shinmoedake Volcano, Kirishima Volcanic Group. Eruption plume reached ca. 7 km in maximum from the vent (Shinbori and Fukui, 2012) and produced extensive andesitic pumice fall deposit extending southeast. Prior to the onset of pumice eruption on 26 - 27th of January, the volcano repeated small phreatic - phreatomagmatic eruptions since 2008 and the pumiceous particles have been already found in these eruptive deposits. Continuous ash emission and intermittent violent explosions followed the pumice eruption and a lava is filling the previous summit crater of the Shinmoedake since 30th of January.

The most of field survey to measure and collect the fall deposits was performed within 4 days after the sub-plinian eruption and revealed that the pyroclastic fall deposit covered an area more than 1000 square km on land and the distribution axis toward N120E. Pumiceous lapilli and blocks are found in the area within 10 km from the volcano. In the area more than 10 km away from the volcano, the fall deposit consists mainly of coarse and fine ash. The distributions for the fall deposits are obtained from field survey measurement at terrestrial region and remote sensing investigations by high altitude-LiDAR for the proximal area around the vent. We estimated total eruptive mass for the fall deposits as ca. 29 MT. Grain size distributions of the fall deposits are consistent with typical sub-plinian deposits on discriminating plot and are prospective to give a total grain size distribution of the sub-plinian eruption from the Shinmoedake.

We are sincerely grateful for providing survey results from TSUTSUI T. (DIA Consultants Co., Ltd.), TAJIMA Y. (Nippon Koei Co., Ltd.), TAKEUCHI S. and TOSHIDA K. (Central Research Institute of Electric Power Industry), HASENAKA T. (Kumamoto University), Japan Meteorological Agency and Public Works Research Institute.

Vesiculation and fragmentation in silicic subaerial and submarine magmas: insights from case studies in the Kermadec arc

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There is debate over the processes involved in the vesiculation and fragmentation of silicic magmas. One aspect is to what extent do the densities and vesicularity characteristics of pyroclasts accurately reflect the point of fragmentation, or whether they have undergone post-fragmentation modification. Here we present pyroclast densities and bubble size and number characteristics from a suite of representative clasts from six silicic eruptions of contrasting size and style from Raoul volcano in the Kermadec arc. Density/vesicularity distributions show a dearth in pyroclasts with 70-75% vesicularity. However, pyroclasts closest to 70-75% vesicularity have the highest bubble number density (BND) values for all eruptions regardless of intensity, style or degree of interaction with external water. Bubble size distributions and BNDs, corrected for clast vesicularity and crystal content, show variations consistent with this vesicularity range representing a critical transition at which vesiculating magma is most likely to undergo fragmentation. Clasts with vesicularity >70-75% have decreasing BNDs, interpreted to reflect bubble coalescence and growth after magmatic fragmentation, but prior to quenching. Clasts with vesicularities <70-75% also have decreasing BNDs but in our examples preserve textures indicative of pre-fragmentation processes such as stalling and volatile loss prior to vesiculation in a microlite-rich magma, or vesiculation during slow ascent of degassing magma. The results of this study, therefore, show that modal density clasts (the usual targets for vesicularity studies) have likely undergone some degree of post-fragmentation vesiculation and are therefore may not be accurately representative of the magma at the moment of fragmentation.

Textures from subaerial erupted Raoul pyroclasts were then compared to similar chemistry submarine erupted pyroclasts sampled via dredging. These results permit inferences to be drawn as to the influence of both eruption rate and water depth on the eruption dynamics, with the interplay between the two playing a vital role. Results of this work challenge the notion of simple end-member explosive or effusive regimes of submarine volcanism and define a new intermediate eruptive style (Tangaroan) that is unique to the subaqueous realm. In contrast, deep submarine higher eruption rate is causes fragmentation to occur within the conduit prior to any quenching influence of the overlying water column. The higher dynamic pressure of a significant overlying water column acting on the eruption jet inhibits rapid decompression and expansion of clasts, as it would if erupted into air, and therefore affects the vesiculation processes and resulting textures in the resulting pyroclasts. The distinctive textural differences seen in subaerial and submarine pyroclasts open up the possibility of being able to fingerprint pyroclasts in ancient volcaniclastic sequences.

Quantification of tephra deposits from Tungurahua 2011 - 2013 eruption, Ecuador: implication on the evolution of a long-lasting eruption

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Since the beginning of the Tungurahua eruption in October of 1999, tephra has been the most frequent and widespread volcanic hazard. Ash clouds have perturbed the air traffic and fallouts have covered thousands of square kilometers on repeated occasions. Quantification of the fallout associated with each eruptive episode is critical in understanding the volcano's eruptive behavior and to assess consequent hazards. We used a network of ash collectors installed around the volcano to collect data on the tephra deposits in 2011 - 2013. Throughout 2012 the ash collectors were replaced with homemade ashmeters that allow for more accurate measurements by reducing error attributed to environmental factors. Eleven sampling missions have been carried out over the course of five fallout periods to assess the evolution of Tungurahua's recent activity: 1) 20 April - 27 May 2011; 2) 27 November - 8 December 2011; 3) 22 December 2011 - 24 July 2012; 4) 5 August - 02 September 2012; and 5) 14 December 2012 - 10 January 2013. The third fallout period is a 7 month span during which Tungurahua volcano developed a semi-continuous complex eruptive dynamism with a proliferation of gentle eruptions. Each of these lasted between one and four days separated by short rest periods. This contrasts with the other four fallout periods that correspond to more continuous eruptions. Both thickness and area density values were collected, however, due to the small amount of fallout during these periods, we used mostly area density to create isomass maps. The total mass of the tephra deposits was calculated using multiple empirical methods after each sampling mission and summarized for each eruptive period. Our results indicate a non-linear reduction of tephra emissions from April 2011 to January 2013. The daily fallout average for each eruption shows a similar pattern. This trend can be extrapolated since the largest eruption of the current active period, in August of 2006, and potentially suggests an approaching end to the volcano's long-lasting eruption. From April 2011 to August 2012 there was also a significant increase of the ratio of SO2 emission/fallout. Assuming that the mass of fallout is fairly proportional to the volume of erupted magma and that the amount of SO2 exsolved from the magma is globally constant, our data would show an increase of the intrusive versus extrusive component during this period. This hypothesis could be tested using seismoacoustic and geodetic data. Continuous quantification of tephra deposits is essential in understanding the evolution of long-lasting eruptions and is a necessary complement to the monitoring system.

Multi-vent/lobe tephra deposition from the 1256 Al-Madinah eruption, Saudi Arabia

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We demonstrate a method for evaluating properties of complex tephra-producing eruptions in basaltic field environments, using a historic example of a 52 day long multistage eruption. The 1256 Al Madinah eruption in Saudi Arabia produced 6 pyroclastic cones, of which the largest three produced significant scoria fall based on recent fieldwork. Tephra dispersal from this eruption had not been investigated since the written accounts of Al Samhoody (1440 - 1506) and Abdul Haq Dehelvi (1551 - 1642). The recent measurements of tephra fall thickness although almost completely unvegetated, show the influence of 800 years spent in a hyper-arid environment. The outermost and finest grained deposits have been partly eroded or reworked, with primary deposit thickness being minimum values only. For deposits <2-3 cm thick, >95% of the material has been redispersed by wind and annual brief rainfall runoff. Coarser, thicker deposits, however, are extremely well preserved.

Our method for estimating tephra attenuation uses actual tephra thickness measurements, incorporating small random perturbations in particle movements due to wind and clast size. The actual thickness observed at any given point differs from an ideal (model) thickness. This difference is termed the *sampling error* and can be explicitly incorporated in the estimation procedure. Since the thickness is strictly nonnegative, and we expect a larger error for larger measurements, a multiplicative error structure is assumed. Hence our focus is the relative error R=O/E, where O is the observed thickness and E is the expected thickness under the model. We consider the Weibull and gamma distributions, which have different tail behaviours, to describe this inherent variability in the tephra thickness measurements.

While the Weibull distribution was a better description of fresh deposits from the 1973 Heimaey and 1977 Ukinrek Maars eruptions, the robustness of this error distribution for ancient and potentially reworked deposits needs to be investigated. This was done by simulating an error distribution of suitable sample size from each distribution. This sample was thinned probabilistically, with thinner (and hence finer) thickness measurements having greater probability of disappearing; this mimics the change in observed tephra thickness over time. Regardless of whether a Weibull or a gamma distribution was simulated, thinning consistently produced an observed sample consistent with a gamma distribution.

We applied our mixture attenuation model with gamma-distributed sampling error to reconstruct the number of eruptive phases from each of the three explosive vents and estimate their sizes, attenuation rates, wind directions and relative strengths. The best description of the event includes four components (accounting for 83% of the total eruptive volume) on the northern vent, one component (8%) on the central vent and one component (9%) on the southern vent.

Transport of pyroclastic particles from 1959 Kilauea Iki eruption in Hawaii

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Details of the dynamics of transport of pyroclasts in Hawaiian fountains still remain unclear. Large pyroclasts are decoupled from the flux of finer particles and gas, and follow parabolic trajectories until they deposit on the ground. These large particles (> c. 10cm) are considered to be ballistic projectiles. It is important to predict the trajectory of such pyroclasts by numerical modeling to mitigate near-vent hazards of Hawaiian eruptions.

The Kilauea Iki 1959 eruption produced the highest fountaining observed among Kilauea historical eruptions. This eruption consists of 17 phases. We focused on the powerful 15th and 16th phases because the dispersal axes of these two phases are the same and we can observe particles of these phases at the ground surface.

According to our previous study, the spacial distribution of large pyroclasts was not produced by fully ballistic transport. If the transport is controlled only by initial velocity, gravity and drag force, larger pyroclasts are transported to farther distances than smaller particles because of their larger inertia. However, the distribution of large pyroclasts in the field shows that the larger particles deposit closer to vent. This means that the transport of larger particles is not purely ballistic. By combining simple calculations, it is shown that the particles are transported vertically by the fountain and then transported laterally.

To model the mechanism of transport made by Hawaiian fountains, we collected not only the size distribution of large clasts but also grainsize distribution of finer material. In the field, there are fine particles everywhere around large clasts. Size distributions of large clasts represent the maximum size of pyroclasts in each limited area. By analyzing spacial distribution of the two types of pyroclasts, we investigated the controlling mechanism of particle transport. Moreover, the results of numerical simulations are compared with these data. In this presentation, we suggest new features of numerical models of particle transport in Hawaiian fountains.

Numerical simulations of atmospheric tephra dispersal at mesoscale - implications for assessment of total erupted mass from the December 2006 and 2009 explosive events at Bezymianny Volcano, Kamchatka

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In explosive eruptions, the total amount of fragmental material and its grain size characteristics are the key parameters commonly used to quantify numerous environmental effects produced by volcanic ejecta. The calculation of total erupted mass (or 'magnitude') of the explosive eruptions is commonly a difficult task, as substantial amount of pyroclastic material comes into the atmosphere in the form of highly fragmented airborne products, known as volcanic ash, subjected to atmospheric dispersal by a spectrum of atmospheric motions that are commonly poorly constrained at mesoscale in a high-mountain area of a volcano location. In this study, we use a lagrangian stochastic Hybrid Particle and Concentration Trasport (HYPACT) model, and Regional Atmospheric Modeling System (RAMS6.0), a state of the art numerical hydrodynamic model, to simulate atmospheric motions and tephra dispersal and fallout at mesoscale for the December 24, 2006, and December 16, 2009, eruptions of Bezymianny Volcano (Kamchyatka). A series of high-resolution numerical experiments was conducted to quantify effects of source geometry, regular advection by wind, turbulent mixing, and particle settling on the spatial distribution of the associated ash-fall deposits. It is shown, that the topography-induced mesoscale perturbations of the synoptic scale background airflow produce first-order effect on tephra-fall patterns in a wide range of particle sizes affecting both coarse and aggregated fine-ash fractions. The model-calculated tephra-fall deposits are compared against field data to assess total erupted mass from, and fine ash content of, these eruptions through linear regression approach. We conclude, that the developed numerical technique, although being not free of some subjective elements, can provide important information on eruption source parameters in addition to commonly used methods of classical sedimentological analyses, as it produces a necessary constrains on atmospheric transport conditions in the both proximal and distal areas around the volcano.

SOURCE DYNAMICS OF PULSATORY ERUPTIONS

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Volcanoes are complex and dynamic systems controlled by the interaction of many processes, whose relations are often non-linear and stochastic. However, these complex systems are not unconstrained and eruptions can show systematic evolutionary trends as well as regular periodic behavior which can be examined in terms of "failure time" through survival analysis. In this study we focus on the dynamics of pulsatory explosive activity and analyze the time interval between single pulses through thermal data and video analysis of Strombolian, violent Strombolian and Vulcanian eruptions. In particular, we focus on data for the explosive eruptions of Cerro Negro (1995), Eyjafjallajokült (2010), Etna (May and July 2012), Fuego (2003), Santiaguito (2003) and Villarrica (2002). The unsteady behavior of these eruptive styles cannot be defined based on their deposits, as the time scale of periodicities cannot be quantified through the stratigraphic record. As a result, classification of eruption style based on the deposit features cannot capture the complexity of unsteady activity. Instead, we characterize the source dynamics based on a statistical analysis of the repose interval, its periodicity and distribution over time, which is viewed as the surface manifestation of the system failure. The repose interval is defined as the time elapsed between the onset of two single pulses, as recorded in thermal data and video footage acquired during each eruption.

Dynamics of unsteady−pulsatory activity can be related to several factors; affecting magma permeability and fragmentation, such as gas segregation, development of fractures, and complex changes in magma permeability. Previous work analyzing the periodicity of pulsatory activity has considered a simple stochastic model: the homogeneous Poisson model. Later, the Weibull distribution was proposed to explain classical failure models, assuming that the probability of eruption increases exponentially with the increase in time interval following the previous eruption. However, many eruptive processes have been broadly explained using the log-logistic distribution. This model describes the processes controlling to the probability of system failure as being due to competing processes influencing the probability of explosion over time. We show the application of various statistical models to the selected eruptions and highlight common features that can aid in the classification of unsteady activity based on source dynamics.

Constraining tephra dispersion and deposition from cyclic subplinian explosions at Shinmoedake volcano, Kyushu, Japan, 2011

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Constraining physical parameters of tephra dispersion and deposition from explosive volcanic events is crucial to quantitatively evaluate eruption dynamics, the process of tephra deposit formation, and resultant hazards, while it is a significant challenge because of difficulties of direct and comprehensive observations in real time. In general theoretical and empirical models or methods are used to study tephra dispersal and physical parameters, in which a large amount of tephra data is required to give improved constraints on modeling results and to reduce uncertainties in estimates of eruption parameters. Although large-scale volcanic eruptions have provided such opportunities to examine theoretical and empirical approaches, small-scale eruptions are more difficult to constrain because smaller volumes of erupted tephra tends to give only a small number of outcrops due to poor preservation of deposits. Data typically needs to be collected soon after an eruption. Thus model applications to relatively small-scale eruptions have not been well studied.

Repetitive subplinian explosions occurred at the andesitic Shinmoedake volcano, Kyushu, Japan, on 26-27 January 2011. Physical parameters (volumes, columne heights and discharge rates) of three subplinian explosions were constrained based on theoretical and empirical approaches for tephra deposits. The volumes of erupted magma was estimated to be 12-21 million m^3 for the 26-27 am eruptions, and 2-4 million m^3 for the 27 pm eruption. Different approaches produced similar results. Based on maximum pumice clast isopleth, clast density and tephra dispersal models, the column height and the mass discharge rate for all three eruptions were estimated to be 7.3-9.4 km a.s.l. and 2-10*10^5 kg/s, respectively. These data is consistent with results from other methods (tephra volume estimation, duration and column height observations). Three subplinian explosions occurred approximately every 12 hours with a decrease of erupted magma volume and with a constant mass discharge rate. This pulsating cycle may be controlled by the chamber-conduit system beneath the Shinmoedake volcano. Deposits from three subplinian explosions don't show clear boundaries corresponding to repose periods but grain size fluctuation. The absence of fine ash layers is probably due to a strong wind which can significantly affect dispersion and deposition of fine particles.

Stratigraphy of 2010 merapi eruption in comparison to previous large deposits

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During the 20th century Merapi had small (VEI 1–3) eruptions every 2–5 years. But in 2010 the volcano had its largest eruption (VEI 3–4) in the last 140 years. Stratigraphy of deposits on the volcano's flanks shows that large eruptions ≥VEI 4 have also occurred in the past, namely at ≥2190yBP, 2190±76 yBP, 300±60 yBP, 1822 and 1872. Although there are some similarities to 2010 and other recent eruptions there are also important differences in comparison to the large eruptions of the past. The 2010 eruption appears less explosive, as indicated by a low vesicularity of juvenile clasts. The 2010 magma also has higher SiO_2 (55–56%). In comparison, the 300 ybp tephra forms thicker deposits and 52–54% SiO_2; juvenile blocks in the 1872 PDC deposit are scoriaceous and lower in silica (51–52%). These factors show that more mafic and gas-rich magmas were involved in the older large eruptions of Merapi and that such magmas were able to traverse Merapi's complex plumbing system more readily in the past than during more recent small eruptions.

As with previous small 20th century eruptions, seismic and deformation precursors for the 2010 eruption started many months in advance; however, unlike the small eruptions, monitoring parameters reached unprecedented levels during the week preceding the 2010 Merapi eruption. The 2010 eruption occurred continuously and reached its peak on 5 November 2010 at 00:05 Western Indonesian Time (WIB). Lengths of pyroclastic flows increased over the course of the eruption: 7.5km (26 October), 9 km (3 November) and they reached a maximum of 16km from the summit during the paroxysmal event. Based on our analysis of the 2010 deposits, the 26 October eruption began with a phreatic phase characterized by coarse ash containing uncharred plants. This was followed by a directed blast to the south and then by pyroclastic flows and ash fall. Additional explosive eruptions took place on 29 October, 31 October, and 1 November. Rapid lava dome extrusion (25 m^3per second) took place at the summit (1 to 4 November) and continued until the paroxysmal eruption, which destroyed the new lava dome, sent an ash column to 17 km altitude and generated PDCs, which reached 16 km from the summit in Kali Gendol. Rapid dome growth (35 m^3per second) resumed on 6 November but ended the same day and the eruption was over by the end of the month. Tephra from the 2010 eruption covered an area of ~765$km^2$and had a relatively small volume of ~19 million m^3(Solikhin et al., in review).

Re-examination of the widespread correlation of Middle Pleistocene tephras in Japan: a co-ignimbrite Ks18 tephra in central Japan and the Shimokado pyroclastic flow deposits, south Kyusyu

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Tephra is one of the best indicators of the history of explosive eruptions. Thus, Middle to Late Pleistocene tephrochronology provides information on regional changes of the frequency, magnitude of eruptions and magma discharge rate as a function of time in a long term. So tephra study of explosive eruptions is one of the most positive approaches to volcanic hazard mitigation.

Shimokado pyroclastic flow deposit (SMPF) erupted from a certain caldera in the southern Kyushu during the middle Pleistocene is one of the stratigraphically important key beds in the whole area of the Japanese Islands. Previous study correlated SMPF to Ks18 tephra (vitric ash fall deposit) in the Kasamori Formation of the Kazusa Group at the Boso Peninsula in central Japan. This pyroclastic flow deposit has been called by various names at each local area in southern Kyushu. In addition, correlation and identification of SMPF in southern Kyushu are controversial among previous studies. Furthermoer, Ks10 tephra above Ks18, both in the Kasamori Formation, is petrographically similar to SPMF, resulting in complication in widespread correlation of SMPF.

In this study, in order to re-examine the correlation of the Shimokado pyroclastic flow deposit between southern Kyushu and central Japan, we revealed the petrographic and chemical properties of eleven pyroclastic deposits (nine pyroclastic flow deposits and two co-ignimbrite ash fall layers), using the following four different criteria; (1) types of glass shards, (2) mineral assemblages, (3) range and modal values of the refractive indices of glass shards and phenocrysts, (4) chemical compositions of the glass shards, hornblende and orthopyroxene. However, in some cases, by the similar pyroclastic deposits of which differences are not clear in these criteria, we examined the possibility of the correlation of the Shimokado pyroclastic flow deposit, taking into account the stratigraphy and ages of these pyroclastic deposits.

The results are as follows:

1. Four pyroclastic deposits (Kuwanomaru pfl, Mikaeri tuff, Matsuyama tuff, Ks18 afa) are correlated with Shimokado pyroclastic flow deposit. These pyroclastic deposits are mostly rich in fiber and sponge types of glass shards and in agreement with their stratigraphically horizons.
2. Three pyroclastic flow deposits (Fumoto pfl, Futami B pfl, Koseda pfl) are distinguished from Shimokado pyroclastic flow deposit by the refractive indices of glass shards and phenocrysts.
3. Compared with each K2O wt% in their volcanic glass shards, Hiwaki pyroclastic flow deposit which was correlated with Shimokado pyroclastic flow deposit by previous study is clearly distinguished from Shimokado pyroclastic deposit. Volcanic glass shards in Hiwaki pyroclastic flow deposit indicate higher K2O ratio.
4. Ks18 and Ks10 which have been indiscernible are easily distinguished by grain size and variation in the chemical compositions of glass shards and hornblende.

Correlating multiple tephra records with heuristic matching

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Establishing a detailed record of past volcanic events is important for probabilistic forecasting. The timing of future events is dependent on what has occurred in the past and hence the accuracy of any forecast relies on the completeness of historical eruption records. Acquiring a detailed record is difficult since tephra dispersal and preservation is highly variable. Using eruption records obtained from a single site can result in an underrepresentation of the frequency of eruptions. However, the use of records obtained from multiple sites is made difficult by the fact that records may contain events in common, as well as events not represented in the other core. Correctly merging eruption records can offer a more complete catalogue of events. However, the combination of data from multiple sources is a statistical problem of some significance.

There is a need for an automated procedure for correlating event records obtained from the radiocarbon dating of tephra deposits. We are developing a system that is based on finding the most feasible set of event matches by employing stochastic local optimization techniques. This sophisticated approach eliminates certain matches through careful reasoning, while heuristically searching over the remaining alternatives. If individual radiocarbon age determinations are judged not to be significantly different then they can be combined by pooling the ages to offer a more precise date of the eruption.

Matches are identified by considering the radiocarbon age and associated age error of each event. Additionally statistical analysis of the titanomagnetite chemistry is used to confirm, or rule out, any possible matches returned by the procedure. This is further complicated by the fact that the algorithm must not violate the stratigraphy of events. The algorithm uses geochemical data but the aim is to adapt the procedure to work with any auxiliary variable.

Our method of identifying plausible matches is demonstrated through the application to stratigraphic records obtained for Mt Taranaki (New Zealand). Data collected from five different sites at different directions around the volcano are used to illustrate the matching procedure and to compile the amalgamated record.

Distribution and character of the 2011 Shinmoedake eruption deposits at Kirishima Volcano, Japan

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Shinmoedake Volcano, in the Kirishima Volcanic Complex, southern Kyushu in southwestern Japan, began a series of eruptions on January 19, 2011. Activity started with a phreatomagmatic eruption, but shifted on January 26 to magmatic eruptions characterized by subplinian eruptions. Lava appeared in the summit crater on January 27, and filled the crater completely by February 2. Multiple vulcanian explosions occurred in the lava-filled crater, and the number of eruptions declined after February 9. The largest vulcanian explosion occurred on March 13, after which relatively small eruptions took place intermittently until September 7, 2011. After April 2011, the frequency of eruptions at Shinmoedake declined to a few times a month. The last eruption occurred from August 31 to September 7, 2011. Subsequent surface unrest has been mild to the present.

The tephra-fall deposits distributed southeast of the vent are divided into five units (unit 1 to 5 in ascending order). Unit 1 is a lithic-rich fine ash-fall deposit occurring on 19 January 2011. Unit 2, formed by subplinian pumice-fall deposits from the evening of January 26 to the early morning of January 27, is the main product of the 2011 eruption. The unit-2 deposit was dispersed throughout an area extending more than 20 km SE of the source crater. Unit 3 comprises tephra-fall deposits related to the January 27 15h41m explosion, and is subdivided into lower (3L) and upper (3U) parts. Unit 3L is a lithic-rich well-sorted coarse ash-fall deposit from the initial stage of the January 27 15h41m eruption, whereas unit 3U is composed mainly of coarse-grained pumiceous lapilli. Unit 4 is a fine ash-fall deposit occurring on January 28-29, and consists mostly of fresh lithic fragments and crystal grains. Unit 5 originates from multiple vulcanian explosions after early February, but most of it derives from the largest vulcanian eruption deposit on March 13. The unit-5 tephra is a lithic-rich medium-to-coarse ash-fall deposit. The 31 August 2011 ash-fall deposit extended 19 km southwest of the Shinmoedake crater; it is fine grained and contains abundant lithic fragments. Temporal variations in grain size and components of the 2011 eruption deposits reveal the eruption sequence and the conditions of the crater, conduit and magma chamber.

Volume estimation of single vulcanian eruption during the activity of Showa crater, Sakurajima Volcano, Japan

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This study evaluates the eruptive volume of individual vulcanian eruption and continuous ash emission from Sakurajima Volcano, southern Kyushu, Japan, based on the detailed distributions of ash deposits. The result shows that continuous ash emission contributes about 77 % of total tephra emission during our observation.

Sakurajima Volcano repeats explosive eruption since 1956. Eruptive activities sifted to Showa crater located at eastern foot of Minamidake crater in 2008, and about one thousand of eruptions per year were observed. Recent activity of Showa crater is characterized with the intermittent explosion (vulcanian explosion) and continuous ash emission.

To evaluate the tephra volume from Sakurajima, we surveyed the tephra distribution in January 2010, February 2011, November 2011, March 2012, and January 2013. We set 30-60 ash traps of paper dish with 15 cm in diameter on a tripod with 20 cm height in the area from 3 to 43 km downwind of the volcano.

We also examine the heterogeneity of ash fall in a single site. We set 8 traps in a single site of 30 x 42 m. The variation of the tephra fall in the traps is less than 25 %.

We obtain distribution (isopleth) maps of 3 vulcanian explosion and 9 continuous ash emission. Based on the distribution map, we calculated the total volume of tephra of every period. The volumes of individual vulcanian eruptions of 1:22 pm of 16 November 2011 and 6:20 am of 6 March 2012 were evaluated as 3,500 t and 25,000 t, respectively. We also detect continuous ash fall during the period between major vulcanian explosions. The tephra volumes during continuous ash emission were calculated to be about 315-1,420 t per hour.

The total volume during our survey in November 2011 (50 hours) was calculated to be 24,306 t. Assuming the average emission rate during repose time as 375 t/h, 18,750 t of ash were emitted without major vulcanian explosion. It corresponds 77 % of the total ash emission during the entire period.

The isopleth maps also show the effect of the distribution of wind-direction on the ash dispersal. The distribution axes of ash fall near the crater are variable due to complex change of wind direction at low altitude. The axes in the distal area tend to extend to the east direction, due to westerlies. The wind direction below 4,000 m a.s.l. is complex, while main wind direction above about 4,000 m is to east during the champagne.

Late Quaternary tephrostratigraphy of the East Asia: implications for the eruptive histories of Baegdusan and Ulleung volcanoes.

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The alkaline tephra-forming volcanoes in and around Japan occur in only two districts, but little is known about the tephrostratigraphy, except U-Oki and B-Tm tephras from the Japan Sea/East Sea. The differences in chemical composition between within-plate alkaline tephras and hemipelagic sediments are usually so large that trace element geochemistry is likely to be useful for particularly alkaline cryptotephra detection in other areas with similar tectonic characteristics. The newly identified tephras (named U-Sado, B-Sado and B-Ym), U-Ym, and B-J tephras were detected and eruption ages identified between AT (29.4 cal. ka) and Aso-4 (87 ka) in five cores based on microscopic observation and the stratigraphic correlations between cores of the Holocene sediments and volcanic glasses from Ulleung and Baegdusan in the East Asia.

The main objective of the present study is to construct an alkaline tephrostratigraphical framework of the late Quaternary in the marine cores that can be integrated with the lithological sediment sequences to better define a regional stratigraphic framework. Major and trace-element data on individual glass shards separated from the detected cryptotephra layers are used to fingerprint the source volcano and confirm regional correlations in East Asia.

Geochemical correlation of marine tephra from Sulu to proximal deposits of active volcanoes in the Philippines

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The study of tephra deposited in the deep sea is important because they provide information on the scale and style of large eruptions, aside from providing samples that would not normally be preserved on land. Sulu Sea, a marginal basin west of the Philippines, is in the downwind direction of several volcanic chains and is a sink for tephra deposits of explosive volcanism. Tephra layers preserved in the Sulu Sea cores taken during the 2006 Marco Polo II cruise were studied to determine their possible source volcanoes using geochemistry. Seven ash layers were identified at 37 to 450 cm depth of the core. Highly vesiculated glass fragments with bubble wall structures were obtained from the ash intervals. The glass fragments were analyzed by EPMA for major elements. Trace elements were obtained by single grain in-situ laser ablation for onland samples and by SIMS for core samples. The glasses from the thicker, light-colored ash layers are rhyolitic (67-77 SiO_2 wt%), those from the thinner, darker ash layers are andesitic to dacitic (52-66 SiO_2 wt%). The geochemistry of ash layers were compared with samples taken from land deposits of known explosive eruptions. Data for ash layers and land deposits formed relatively tight clusters on incompatible element discrimination diagrams, implying an eruptive rather than turbidite origin for all ash layers except one at 337 cm. Onland tephra showed enrichment in light rare earth elements with a positive Ce anomaly, whilst the marine tephra were observed to have enrichment in the heavy rare earth elements. Detailed inspection of the trace element data reveal that the rhyolitic ash layers may have an affinity with Bulusan volcano deposits whereas the basaltic-andesitic layers have similar composition with those of younger Mayon airfall deposits. While several layers preserved in the core appear to be cogenetic and related to a specific source volcano, others still require distinct sources from those already identified in this study. Alternatively, they may reflect variations in the source volcano magma compositions which are not preserved on tephra deposits onshore.